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COMPACT WIDEBAND BANDPASS FILTER WITH QUADRUPLE-MODE STUB-LOADED RESONATOR

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Abstract—In this letter, a novel compact wideband bandpass filter (BPF) is proposed using quadruple-mode resonator formed by attaching a short-circuited stub at the center plane and two identical impedance-stepped open stubs to high impedance microstrip line. The resonator can generate two even-modes f_{m1}, f_{m3} and two odd-modes f_{m2}, f_{m4} in the desired band. The even-mode resonant frequencies can be flexibly controlled by the short-circuited stub, whereas the odd-mode ones are fixed. When the open stubs are attached to the center plane nearby, they can be mainly applied to adjust f_{m3}, f_{m4} into desired passband as the high odd-mode and even-mode resonant frequencies are vulnerable to their electronic lengths. Two transmission zeros near the lower and upper cut-off frequencies are separately created by the short-circuited stub and interdigital feeding lines, leading to a high rejection skirt. A wideband BPF with the fractional bandwidth 64% is simulated, fabricated and measured. The measured results agree well with the EM simulations.

1. INTRODUCTION

As wireless communication technology makes a rapid development, compact microstrip filters with high frequency selectivity and wide stopband are highly demanded [1, 2]. Resonators, as the fundamental elements in a filter, usually determine the size of the filter. There are many ways to reduce the resonator size. An important way for the filter size reduction is to modify the traditional resonator to

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generate additional modes, causing the resonator to have multiple resonant frequencies, and thus one physical resonator can be treated as multiple electrical resonators. Examples can be seen from dual-mode ring resonator [3], dual-mode square-ring resonator [4] and dual-mode multi-arc resonator [5]. The dualmode means two degenerate resonant modes of the aforementioned geometrically symmetrical resonators and the two degenerate resonant modes may be split by introducing a perturbation element in a resonator. Subsequently, the dual-mode resonator that odd and even modes do not couple has been given in [6]. Some triple-mode resonators [7, 8] have been presented to design BPFs with high frequency selectivity. However, the fractional bandwidths of the BPFs are less than 5%. Recently, several BPFs with the fractional bandwidth better than 110% are reported using the triple-mode steppedimpedance resonators (SIR), such as stub-loaded MMR [9], EBG-embedded MMR [10], one open stub and one short stub loaded MMR [11]. Then, a quadruple-mode SIR by Wong and Zhu [12] is proposed to build up UWB filter with compact size. In [13], instead of using multimode SIR, a dual-mode resonator composed of single stub at the center plane and two sections of transmission lines is introduced for high rejection and wideband BPF with the fractional bandwidth 45%.

In this letter, a novel quadruple-mode stub-loaded resonator is applied to design a compact wideband BPF shown in Fig. 1. The resonator can generate two odd-modes and two even-modes in the desired band. The even-mode resonant frequencies can be flexibly controlled by the short-circuited stub at the center plane, whereas the odd-mode ones are fixed. As the open stubs are attached to the center plane nearby, they can be mainly applied to adjust the high resonant frequencies f_{m3}, f_{m4} into desired passband and have less impact on the f_{m1}, f_{m2}. Two transmission zeros near the lower and upper cut-off frequencies are separately created by the short-circuited stub and the interdigital feeding lines, leading to a high rejection skirt. Finally, one

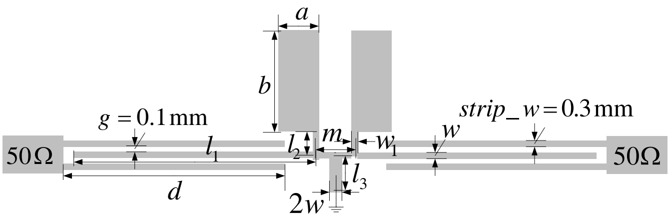


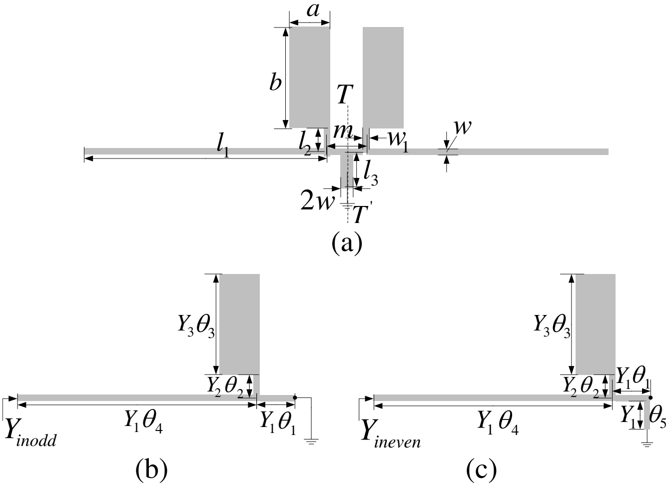
Figure 1. Schematic of the proposed quadruple-mode wideband BPF.

wideband BPF prototype is fabricated for experimental verification of the predicted results. The substrate is RT/Duroid 5880 with a thickness of 0.508 mm, permittivity of 2.2 and loss tangent 0.0009.

2. PROPOSED QUINTUPLE-MODE STUB-LOADED RESONATOR

A quadruple-mode resonator configured by adding two identical impedance-stepped open stubs denoted by lengths (b, l_2) and widths (a, w_1) and a short-circuited stub (l_3, $2w$) to high impedance microstrip line with length of $2l_1 + m$ and width of w is shown in Fig. 2(a). Since the resonator is symmetrical to the T-T' plane, the odd-even-mode method is implemented. Voltage (current) vanishes in the T-T' plane, leading to the approximate transmission line circuit models represented in Figs. 2(b) and (c). Referring to Fig. 2, θ_1, θ_2, θ_3, θ_4, and θ_5 refer to the electrical lengths of the sections of lengths $m/2$, l_2, b, l_1, and l_3, respectively. And Y_1, Y_2, and Y_3 refer to characteristic admittances of the widths w, w_1, and a, respectively. From the condition $Y_{inodd} = 0$ and $Y_{ineven} = 0$, the resonant frequencies of the odd and even excitations in Fig. 2(a) and Fig. 2(b) can be extracted [6] (we suppose $w = w_1$):

$$(\tan\theta_1 \tan\theta_4 - 1)(Y_1 - Y_3 \tan\theta_3 \tan\theta_2) + \tan\theta_1 (Y_3 \tan\theta_3 + Y_1 \tan\theta_2) = 0 \qquad (1)$$



(a)

(b) (c)

Figure 2. (a) Structure of quadruple-mode stub-loaded resonator, (b) odd-mode equivalent circuit, and (c) even-mode equivalent circuit.

$$
\begin{aligned}
&(\tan(\theta_1+\theta_5)\tan\theta_4-1)(Y_1-Y_3\tan\theta_3\tan\theta_2)\\
&+\tan(\theta_1+\theta_5)(Y_3\tan\theta_3+Y_1\tan\theta_2)=0
\end{aligned}
\tag{2}
$$

We may choose the parameters of the impedance-stepped open stub and short-circuited stub: $a = 2\,\mathrm{mm}$, $b = 5\,\mathrm{mm}$, $l_2 = 1\,\mathrm{mm}$, $w_1 = 0.3\,\mathrm{mm}$, and $l_3 = 1.8\,\mathrm{mm}$. With the total parameters $2l_1 + m = 25.4\,\mathrm{mm}$ keeping unchanged, resonant-mode frequencies varied m from formulas (1) and (2) are interpreted in Fig. 3. It can be seen that there are two odd modes and two even modes in the range of 0.1–7.5 GHz, and the length m can adjust their locations. When the open stubs move towards the center plane, they basically have no impact on the odd mode frequency f_{m2}. So, the f_{m2} is approximately determined by the following expression:

$$
f_{m2} = \frac{c}{2(2l_1+m)\sqrt{\varepsilon_{\mathit{eff}}}}
\tag{3}
$$

where c is the speed of light, and $\varepsilon_{\mathit{eff}}$ is equivalent to dielectric constant.

Furthermore, the effects of the length b and width a of the impedance-stepped open stubs are separately investigated and shown in Fig. 4 and Fig. 5, where m is equal to 0.95 mm on account of the little coupling between the open stubs. According to Fig. 4 and Fig. 5, the common characteristic can be found that as the b and a increase, the high resonant frequencies f_{m3}, f_{m4} tend to shift downwards, and the f_{m1}, f_{m2} remain relatively stationary.

Even-mode resonant frequencies varied l_3 are interpreted in Fig. 6, for the reason that the short-circuited stub at the center plane merely controls the even-mode resonant frequencies. As the length l_3 of the short-circuited stub increases from 0.1 mm to 3 mm, two even-mode resonant frequencies in Fig. 6 move towards the lower frequency.

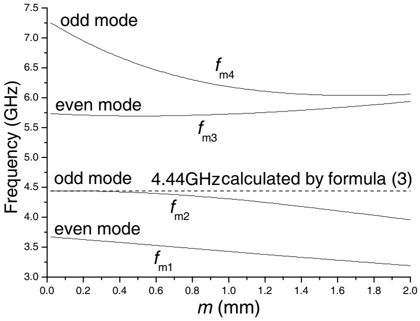


Figure 3. Resonant-mode frequencies with varied m.

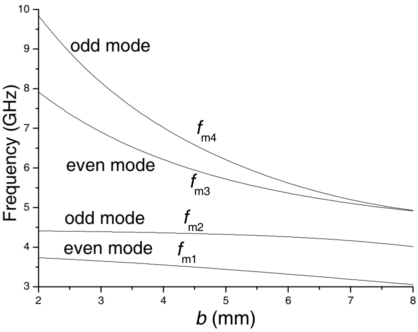


Figure 4. Resonant-mode frequencies with varied b.

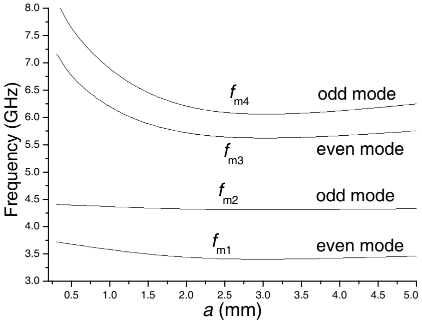


Figure 5. Resonant-mode frequencies with varied a.

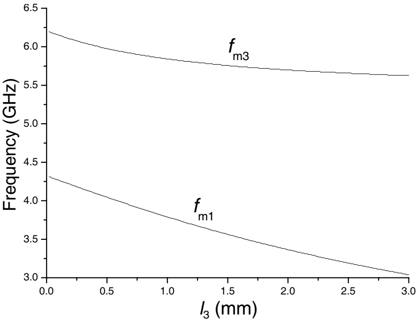


Figure 6. Resonant-mode frequencies with varied l_3.

Thus, the second resonant frequency can be allocated in the center frequency of the passband by reasonably choosing l_1 and m, and the other three resonant frequencies can be adjusted within the desired passband by simply varying the parameters a, b, and l_3.

3. QUINTUPLE-MODE STUB-LOADED WIDEBAND FILTER

The quadruple-mode resonator coupled to $50\,\Omega$ input/output interdigital feeding lines under the selected coupling lengths of $d = 0.3$ mm (the weak coupling case) and $d = 11.1$ mm (the tight coupling case) [9] is simulated by HFSS and shown in Fig. 7, where g=0.1 mm, strip_w = 0.3 mm, $a = 2$ mm, $b = 5$ mm, $l_2 = 1$ mm, $w = 0.3$ mm, $w_1 = 0.3$ mm, $l_3 = 1.8$ mm and $m = 0.95$ mm. The first four simulated resonant-mode frequencies ($f_{m1} = 3.09$ GHz, $f_{m2} = 4.20$ GHz, $f_{m3} = 5.35$ GHz, and $f_{m4} = 5.86$ GHz) under the weak coupling case can work together to make up a wideband BPF, if the resonator is properly fed with increased coupling degree [9–12]. Under tight coupling case, two transmission zeros T_{z1}, T_{z2} near the lower and upper cut-off frequencies are separately created by the short-circuited stub and interdigital feeding lines [9, 12], leading to a high rejection skirt. The other transmission zero T_{z3} is excited by the open stubs to deepen the upper-stopband [12].

After studying the characteristic of the wideband BPF, the filter is fabricated on the RT/Duroid 5880 substrate, and its photograph is shown in Fig. 8. The filtering performance is measured by Agilent network analyzer N5230A. The measured $|S_{11}|$ in dB and $|S_{21}|$ in dB as well as group delay are shown in Fig. 9 and in good agreement with

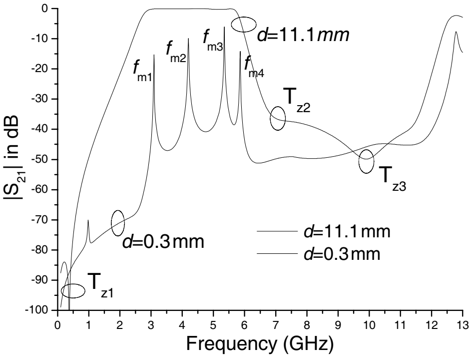


Figure 7. Simulated frequency responses of the quadruple-mode resonator with $d = 0.3\,\text{mm}$ and $d = 11.1\,\text{mm}$.

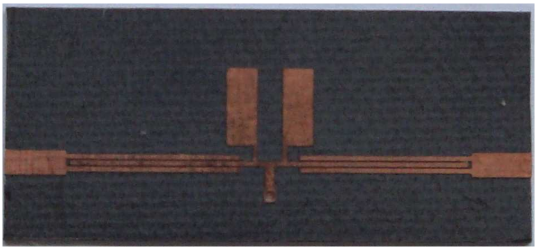
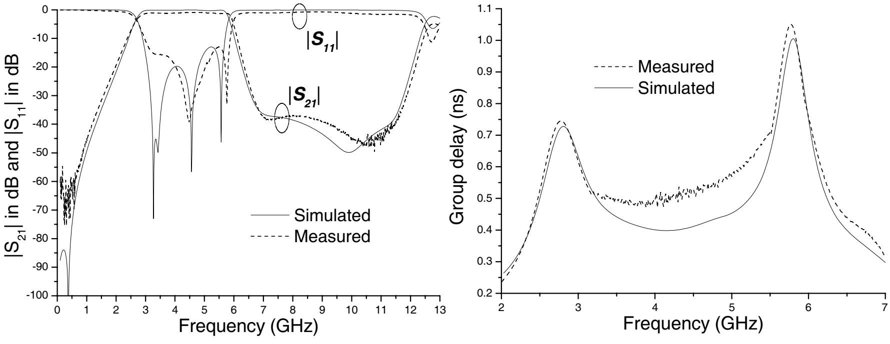


Figure 8. Photograph of the fabricated wideband BPF.



(a) (b)

Figure 9. Simulated and measured frequency responses of the quadruple-mode wideband BPF. (a) $|S_{21}|$ in dB and $|S_{11}|$ in dB. (b) Group delay.

simulated results. The measured 2 dB passband is in the range of 2.95 to 5.73 GHz, and its measured input return loss ($|S_{11}|$ in dB) is less than −12.1 dB. The upper-stopband in experiment is extended up to 12.3 GHz with an insertion loss better than −30 dB. In addition, the measured in-band group delay varies from 0.5 to 0.93 ns, which is quite small and flat in all the passband.

4. CONCLUSION

A novel compact wideband BPF with quadruple-mode stub-loaded resonator is proposed in this letter. The resonator can generate two odd-modes and two even-modes in the desired band. The even-mode resonant frequencies can be flexibly controlled by the short-circuited stub, whereas the odd-mode ones are fixed. As the open stubs are attached to the centre plane nearby, they can be mainly applied to adjust the high resonant frequencies f_{m3}, f_{m4} into desired passband and have less impact on the f_{m1}, f_{m2}. Two transmission zeros near the lower and upper cut-off frequencies are separately created by the short-circuited stub and the interdigital feeding lines, leading to a high rejection skirt. Based on the resonator, a wideband BPF with the fractional bandwidth 64% is designed to exhibit its attractive sharp rejection skirts and wide upper-stopband. A filter prototype is fabricated to demonstrate the predicted performances in experiment.

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